NOTES BY THE EDITOR.

THE RAINFALL AND OUTFLOW OF THE GREAT LAKES.

In a complete study of the rainfall over the Great Lakes, the variations in their surface levels, and the eventual discharge at the respective outlets, the following items have to be considered:

(*a*) The total amount and distribution throughout the year of the rainfall and melted snow on the lake surface.

(*b*) The run off from the watershed into the lake, which, of course, depends upon the rainfall and snowfall minus the evaporation and consumption.

(*c*) Evaporation from the lake surface itself.

(*d*) The outflow or discharge from the lake.

(*e*) The effect of the current winds in temporarily changing the level, and also the effect of the average wind in permanently changing the level of the water.

(*f*) The small variable effects of solar and lunar tides, changes of the earth's axis, variations of barometric pressure, varying temperature, and density of the water.

(*g*) The secular changes due to gradual geological changes by which the earth's surface is being slowly tipped in one direction or another,[1] as also those due to silting up of the shallow and quiet portions, and those due to the wearing away of the channels and banks. These secular changes may be appreciable in fifty years, but as compared with the variations of rain and snow, evaporation, and winds, they have no importance in annual means.

In general, the experience of the past three hundred years has shown that the surfaces of the various lakes have oscillated up and down through a range of several feet about a mean position that must represent very closely the normal balance between the annual income and outgo for the present century. So far as the atmosphere is concerned the normal *supply* is not likely to change, but the normal *outflow* is subject to considerable variations and to a slow secular increase that may eventually lower the levels of the surfaces of the lakes.

[1] According to Mr. G. K. Gilbert, there is at present going on a gradual change in inclination of the general surface of the land, by reason of which the whole Lake Region is, relatively speaking, sinking in its southwestern half and rising in its northeastern half. The following quotation is taken from an advance copy of the forthcoming report by Mr. Gilbert in the Annual Report of the Director of the United States Geological Survey:

"The land in this region is being slowly canted toward the south-southwest, and the rate of change is such that the two ends of a line 100 miles long and lying in a south-southwest direction are relatively displaced by four-tenths of a foot in 100 years. The waters of each lake are gradually rising on the southern and western shores, or falling on the northern and eastern shores, or both. This change affects the mean height of the lake surface. In Lake Ontario the water is advancing on all shores, the rate at any place being proportional to the distance from the isobase through the outlet. At Hamilton and Port Dalhousie it amounts to 6 inches in a century. The water also advances on all shores of Lake Erie, most rapidly at Toledo and Sandusky, where the change is 8 or 9 inches per century. All about Lake Huron the water is falling most rapidly at the north and northeast, where the distance from the Port Hudson isobase is greatest. At Mackinac the rate is 6 inches, and at the mouth of French River, 100 inches per century. On Lake Superior the isobase of the outlet cuts the shore at the international boundary; the water is advancing on the American shore and sinking on the Canadian. At Duluth the advance is 6 inches, and at Heron Bay the recession is 5 inches per century. The shores of Lake Michigan are divided by the Port Hudson isobase. North of Oconto and Manistee the water is falling. South of those places it is rising, the rate at Milwaukee being 5 or 6 inches per century, and at Chicago 9 or 10 inches. Eventually, unless a dam is erected to prevent, Lake Michigan will again overflow to the Illinois River, its discharge occupying the channel carved by the outlet of a pleistocene glacial lake. The summit in that channel is now 8 feet above the mean level of the lake, and the time before it will be overtopped (under the stated assumption as to the rate of tilting) may be computed."

A satisfactory study of important points relative to this subject would require an elaborate collection of new data and its consideration from this special point of view, a work that will undoubtedly be carried out by the engineers of United States Deep Waterways Commission.

From the general climatological point of view it is believed that the most that can be said at the present time, as to the general régime of the lakes, may be condensed into the following text and tables.

The extensive tables published on pages 129–143, of the report of the United States Deep Waterways Commission, show the average elevation of the lake surface at numerous points, month by month, since accurate records began, generally about 1860. In order to understand the reason for the monthly variations it will be necessary to compile a table showing the rainfall and *accumulated* rainfall, month by month and year by year, over the lake surface; the same items as to evaporation from the lake surface; the same items as to run off from the watershed; finally, the same items as to outflow from the lakes, which latter, of course, varies principally with the height of the water at the outlet itself. At the present time we know none of these separate items with anything like the accuracy that is necessary and of course, therefore, we can only predict in a very general way the effect that will be produced by the addition of engineering works to the present natural system.

The outflow from each lake has been measured at several times and the results, as quoted by G. Y. Wisner (First Annual Convention of the International Deep Waterways Association, page 126), are as follows:

1.—Lake Superior, 86,000 cubic feet per second, or 36.74 inches in depth over the whole surface of Lake Superior per year.

2 plus 3.—Lake Michigan plus Lake Huron, 225,000 cubic feet per second, or 67.02 inches in depth per year. There is no sensible difference between these two lakes, and they must be treated as one.

2 plus 3 plus 4.—Lake Michigan plus Lake Huron plus Lake St. Clair, 230,000 cubic feet per second, or 67.00 inches per year.

5.—Lake Erie, 265,000 cubic feet per second, according to Mr. D. F. Henry, but 230,000 cubic feet per second according to Mr. Ruffner of the United States Engineers. The average of these is 250,000 which will be assumed as a mean annual outflow. According to the records in the Annual Report of the Chief of Engineers for 1893, p. 4367, the observations between December, 1891, and May, 1892, show the following large range, namely, 1891, December 24, at low water stage, 164,648 cubic feet per second, and 1892, May 23, at a high stage, 239,677 cubic feet per second. It would seem that a much longer series of observations is necessary in order to determine the normal discharge and that our adopted figures may easily be 10 per cent too large.

6.—Lake Ontario, 300,000 cubic feet per second.

As I do not know of any more accurate measurements of discharge and presume that all these figures will be revised in the next report of the United States Deep Waterways Commission, I will make these the basis of a preliminary computation. The details of the steps as we proceed down the chain of lakes are given in full in Table 1 and may be explained as follows:

LAKE SUPERIOR.

The map of annual normal distribution of rain and melted snow shows that about 31.2 inches of rain falls on the surface of the lake as well as on that of its watershed. Of this latter quantity about 25 per cent may be estimated as run off into the lake, the remainder is absorbed by the ground or evaporated into the air. This adds 7.8 inches in depth for the whole area of the watershed, but as the surface of the lake is smaller than that of the watershed, this is equivalent to 11.9 inches for the whole area of Lake Superior. As there is no inflow from an upper lake this gives 11.9 + 31.2 = 43.1 inches in depth, as the annual supply over the whole surface. It is estimated that the annual evaporation takes off 15.0 inches, thus leaving 28.1 as a normal annual addition to the depth of the lake. If the lake is to maintain its level without change this available surplus must be counterbalanced by an equal outflow through the St. Mary's River. The actual outflow has been measured frequently, and as quoted above from Wisner, will first be assumed as 86,000 cubic feet per second. It is most convenient to convert this measured discharge per second into the corresponding depth of water run off from the whole lake during the year, which is easily done as follows: The observed or approximate discharge of Lake Superior in cubic feet per second, divided by the number of square feet in the surface of the lake, will give the equivalent linear depth by which the water must fall in one second, viz, 86,000/31,800 × 5,280 × 5,280; multiplying this by the number of seconds in a year, i. e., 86,400 × 365.25, we obtain the *annual* discharge expressed as a depth of water over the whole surface of the lake in feet (or multiplying by 12, in inches). The result is—for Lake Superior—36.736 inches, which we have inserted in line 13 in Table 1.

LAKE MICHIGAN + HURON.

Similarly the discharge of Lake Huron, or more properly Lake Michigan + Lake Huron, 22,500 cubic feet per second, becomes, in depth for the whole surface of the lake, 67.02 inches, as given in Table 1, line 13, for Michigan + Huron.

The surplus of 28.1 inches from Lake Superior when distributed over Michigan + Huron becomes 28.1 × 31,800 / 45,600, or 18.75 of an inch in depth. The total supply of Michigan + Huron is 50.95, adding the inflow, 18.75, and subtracting the evaporation, 21.60, we have an available surplus of 48.10. The measured outflow, 67.02, exceeds this in about the same ratio as for Lake Superior.

ERIE.

Assuming that the surplus from Michigan + Huron, increased by the annual supply minus the evaporation for Lake St. Clair, is the total annual inflow into Lake Erie, we have to spread the sum of these two items over the area of Lake Erie. The two items of inflow are respectively:

From Lake Michigan + Huron...... 48.75 × 45,600 / 10,000 or	221.4
From Lake St. Clair..................124.0 × 495 / 10,000 or	6.14
Total inflow..	227.5

This inflow into Lake Erie, added to its total supply and diminished by the annual evaporation, gives an available surplus of 263.5 inches in depth.

The measured outflow from Lake Erie is 250,000 cubic feet per second, with a large uncertainty, or 339.6 inches in depth annually, which as before is about 30 per cent in excess of the computed available surplus.

ONTARIO.

The surplus from Lake Erie, 263.5 multiplied by the ratio of the areas, viz, 10,000 / 7,450, gives 353.7 for the equivalent depth on Lake Ontario; this latter, increased by the supply and diminished by the evaporation, gives 389.1 as the available surplus from Lake Ontario.

The measured outflow from Lake Ontario is given as 300,000 cubic feet per second, or 547.0 inches in depth per year. This again is over 40 per cent in excess of the available surplus.

IN GENERAL.

We thus see that throughout the whole chain of lakes our computations of possible normal available surplus per annum, computed for estimated values of the normal annual rainfall and evaporation, and very crude estimates of the run off from the watersheds, have invariably given values that are decidedly too small as compared with the measured outflow. It is very hazardous to speculate on the reason for this systematic discrepancy. If there is any truth in the measured outflows, rainfalls, and evaporations, then we must attribute the discrepancy to our ignorance of the percentage of run off from the watersheds. But as the evaporation is only estimated and has not yet been measured there is at present no need of suggesting new hypotheses, such as underground springs, to explain the discrepancy.

We might diminish the estimated loss by evaporation by 10 per cent and increase the rainfall by 10 per cent, and diminish the measured outflow, on the assumption that it relates to special years and not to normal values. In fact, the whole computation ought to be made for the specific years for which we have measured outflows and rainfalls.

It will be worth while to repeat all the preceding computation on the assumption that the percentage of the run off is 50 in place of 25, and this I have done in the last column of Table 1. Of course, the agreement between surplus and outflow is in general much improved, but whether this is a correct step toward the solution of the difficulty can only be determined when we have accumulated much better and more numerous observations than we now have. It is safe to conclude that the meteorological data as to rainfall are at present more accurate than the engineering data, i. e., evaporation, run off, inflow, and outflow.

With regard to the specific question as to the influence of the canal at Chicago, as planned by the Sanitary Commission, I find that the engineer, L. E. Cooley, on page 361 of the first report of the I. D. W. A., accepts 10,000 cubic feet per second as the probable outflow at Chicago. The effect of this outflow on the general level of Lake Huron plus Michigan will, of course, be 10,000 / 225,000 by the present outflow, which is 67.02 linear inches in depth annually; the result is 3 inches, so that the future outflow will be 70 instead of 67 inches. The effect of this upon the depth of water of Michigan plus Huron, and on the outflow of Lakes St. Clair, Erie, and Ontario, will be barely appreciable and of no practical importance whatever, in comparison with the uncertainty, the variability, and the great importance of the rainfall and evaporation. This slight drain upon Lake Michigan will undoubtedly be supplied by Lakes Superior and Huron, without affecting the surface level of St. Clair or Erie by more than a small fraction of an inch.

The deepening of the channel through St. Clair and Detroit rivers will diminish the resistance to the flow of water, so that more will pass per second than before, provided "the head of water," namely, the difference in level between Huron and Erie, remains the same; but this will not be the case. The effect will be felt at first mostly in the very center of the channel, and the total annual discharge will at first be a little, namely, much less than 1 per cent, more than at present; it may increase from 230,000 to 232,000 cubic feet per second, or from 67.00 to 67.6 inches per annum, but the final result will be the same as if we opened a wider and easier communication between the two lakes, and they will come to the same level and act as one lake, just as Huron and Michigan do now. Therefore, it is that we have given a computation in Table 1 for the three lakes combined.

As the influence of these two proposed engineering improvements on the régime of the lake is so small compared with that of the natural forces at work, it is evident that it is especially important to accumulate and improve the climatological data, rainfall, and evaporation, barometric pressure, and winds, all of which affect the supply and the outflow. These are vastly more important to the general public than are the local engineering projects, and the latter may be prosecuted without fear of disturbing the natural status of affairs.

TABLE 1.—*The computed regimen of the Great Lakes.*

(1) LAKE SUPERIOR.

1. Area of watershed, square miles	48,600	.....
2. Area of water surface, square miles	31,800	.....
3. Factor: Watershed / lake surface	1.528	.....
4. Annual rainfall on watershed, inches	31.2	.....
5. Average run off, percentage	25.0	50.0
6. Equivalent depth on watershed, inches	7.8	15.6
7. Equivalent depth on lake surface, inches	11.9	23.9
8. Annual rainfall on lake surface, inches	31.2	31.2
9. Annual inflow in depth, inches	0.0	0.0
10. Total supply in depth, inches	43.1	55.1
11. Annual evaporation in depth, inches	15.0	15.0
12. Available surplus, inches	28.1	40.0
13. Measured outflow, inches	36.7	.....
14. Ratio: Outflow / surplus	1.31	.....

(2) LAKE MICHIGAN.

1. Area of watershed, square miles	45,700	.....
2. Area of water surface, square miles	22,400	.....
3. Factor: Watershed / lake surface	2.040	.....
4. Annual rainfall on watershed, inches	33.6	.....
5. Average run off, percentage	25.0	50.0
6. Equivalent depth on watershed, inches	8.4	16.8
7. Equivalent depth on lake surface, inches	17.1	34.3
8. Annual rainfall on lake surface, inches	33.6	33.6
9. Annual inflow in depth, inches	0.0	0.0
10. Total supply in depth, inches	50.7	67.9
11. Annual evaporation in depth, inches	21.6	21.6
12. Available surplus, inches	29.1	46.3
13. Measured outflow, inches	....	.....
14. Ratio: Outflow / surplus	....	.....

(2)+(3) LAKE MICHIGAN PLUS HURON.

1. Area of watershed, square miles	97,800	.....
2. Area of water surface, square miles	45,600	.....
3. Factor: Watershed / lake surface	2.145	.....
4. Annual rainfall on watershed, inches	33.6	.....
5. Average run off, percentage	25.0	50.0
6. Equivalent depth on watershed, inches	8.4	16.8
7. Equivalent depth on lake surface	18.0	36.0
8. Annual rainfall on lake surface, inches	33.6	33.6
9. Annual inflow in depth, inches	18.75	27,9
10. Total supply in depth, inches	70.35	97.5
11. Annual evaporation in depth, inches	21.6	21.6
12. Available surplus, inches	48.75	75.9
13. Measured outflow, inches	67.02	.....
14. Ratio: Outflow / surplus	1.38	.....

(2)+(3)+(4) LAKE MICHIGAN PLUS HURON PLUS ST. CLAIR.

1. Area of watershed, square miles	104,190	.....
2. Area of water surface, square miles	46,095	.....
3. Factor: Watershed / lake surface	2.259	....
4. Annual rainfall on watershed, inches	34.0	.....
5. Average run off, percentage	25.0	50.0
6. Equivalent depth on watershed, inches	8.5	17.0
7. Equivalent depth on lake surface, inches	19.20	38.3
8. Annual rainfall on lake surface, inches	34.0	34.0
9. Annual inflow in depth, inches	19.5	27.9
10. Total supply in depth, inches	72.7	100.2
11. Annual evaporation in depth, inches	21.7	21.7
12. Available surplus, inches	51.0	78.5
13. Measured outflow, inches	67.0	.....
14. Ratio: Outflow / surplus	1.31	.....

(5) LAKE ERIE.

1. Area of watershed, square miles	24,480	.....
2. Area of water surface, square miles	10,000	.....
3. Factor: Watershed / lake surface	2.448	.....
4. Annual rainfall on watershed, inches	37.2	.....
5. Average run off, percentage	25.0	50.0
6. Equivalent depth on watershed, inches	9.3	18.6
7. Equivalent depth on lake surface, inches	22.8	45.6
8. Annual rainfall on lake surface, inches	37.2	37.2
9. Annual inflow in depth, inches	235.1	406.0
10. Total supply in depth, inches	295.1	488.8
11. Annual evaporation in depth, inches	24.0	24.0
12. Available surplus, inches	271.1	464.4
13. Measured outflow, inches	339.6	.....
14. Ratio: Outflow / surplus	1.31	.....

(6) LAKE ONTARIO.

1. Area of watershed, square miles	25,530	.....
2. Area of water surface, square miles	7,450	.....
3. Factor: Watershed / lake surface	3.427	.....
4. Annual rainfall on watershed, inches	33.6	....
5. Average run off, percentage	25.0	50.0
6. Equivalent depth on watershed, inches	8.4	16.8
7. Equivalent depth on lake surface, inches	29.2	58.4
8. Annual rainfall on lake surface, inches	33.6	33.6
9. Annual inflow in depth, inches	364.0	620.3
10. Total supply in depth, inches	426.8	712.3
11. Annual evaporation in depth, inches	24.0	24.0
12. Available surplus, inches	402.8	688.3
13. Measured outflow, inches	547.0	.....
14. Ratio: Outflow / surplus	1.392	.....

MOUNTAIN STATIONS IN AUSTRALIA.

The following extract from a letter addressed to the Chief of the Weather Bureau, by Clement L. Wragge, Government Meteorologist, Brisbane, Queensland, Australia, dated February 7, 1898, shows that mountain meteorology is not to be confined to the Northern Hemisphere and the great continents, but will be prosecuted wherever mountain peaks can be found. We also infer that the Australian stations on Mount Wellington and Mount Kosciusko represent a general attack upon the problem of upper currents in which the whole of Australia, and not merely any one district, is interested. Indeed, for that matter, the whole Northern Hemisphere is interested in what goes on in the upper regions of the Southern Hemisphere, and we wish every success to Mr. Wragge's enterprise and to all similar efforts:

I have much pleasure in informing you that, on the 9th of December last, I established an experimental meteorological observatory on Mount Kosciusko, 7,328 feet, the highest mountain in New South Wales; and by January 1, a similar station correlative thereto was also established near the sea level at Merimbula, in New South Wales. Simultaneous observations are taken at both stations every four hours, commencing at midnight; and also, as a special series, half-hourly, between 8 a. m. and noon, on the original Ben Nevis lines. Simultaneous readings are also taken at Sale, in Victoria, near the sea level, and also at a special station established by me in the city of Sydney. Simultaneous observations are further taken (with the exception of those at the half-hours) at Hobart, on the summit of Mount Wellington, and at the Half-way Station. I sincerely trust that the results will prove of value to meteorology.

The principal donors to the Kosciusko scheme are Mr. Barr-Smith, of Adelaide, and the Honorable G. H. Reid, premier of New South Wales, as representing the New South Wales Government.

I hope to be able to make arrangements for the continuation of the mountain station during the winter months, but am not, as yet, quite sure on that point. At any rate, the Kosciusko experiment will be repeated at the close of the coming winter. You will see full accounts by the various newspapers which you will receive in due course, and this letter must be taken as my official intimation.

TIN ROOFS AS LIGHTNING CONDUCTORS.

A recent letter from Dr. John W. Kales, of Franklinville, N. Y., describes a terrific thunderstorm at that place on May 19, on which occasion several persons within houses were